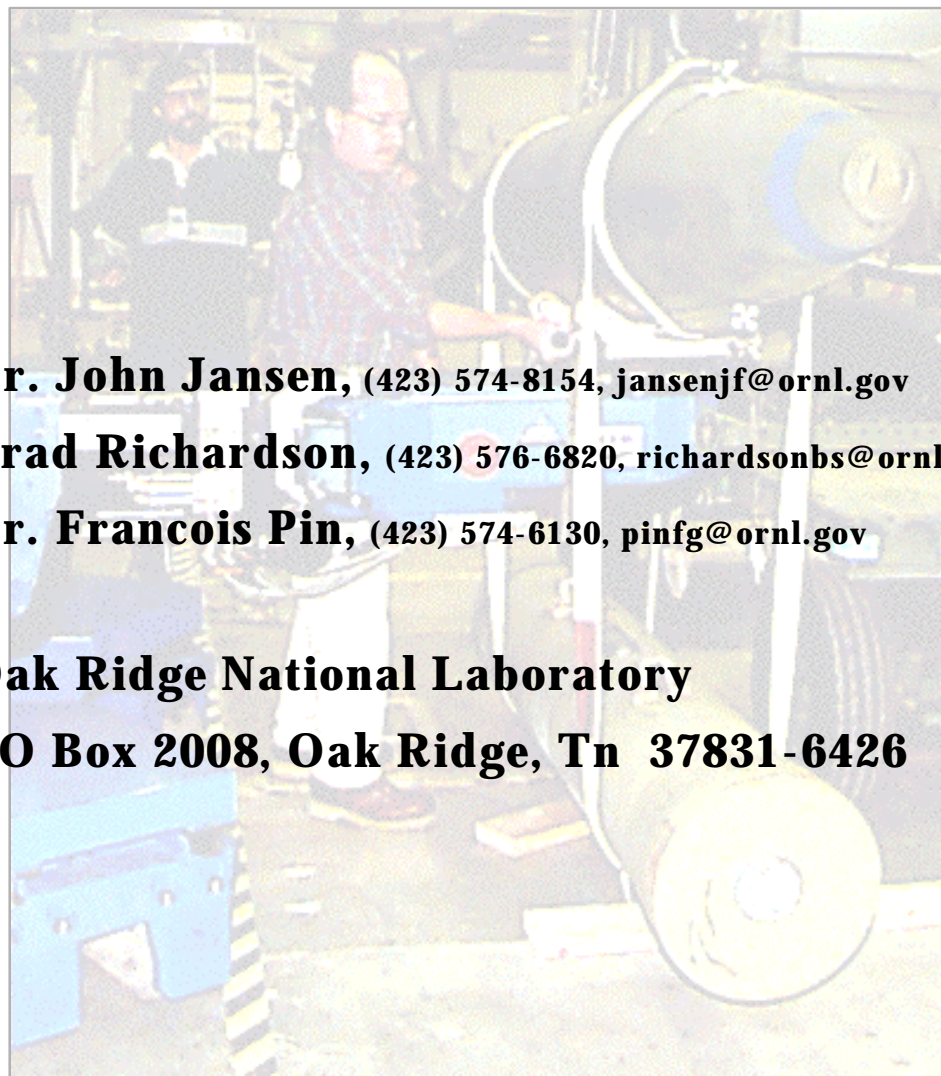




ORNL's Human Amplification Systems



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Hardiman: Control Concepts

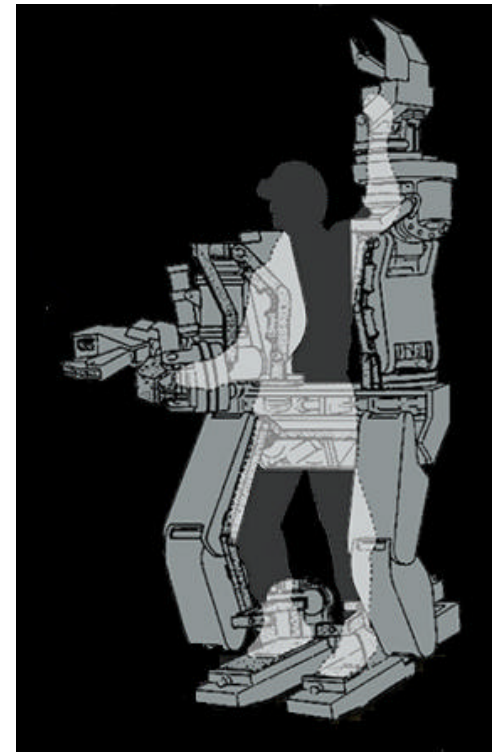
(Implemented Using '60s Technology)

- “...The first master-slave configurations were based on ideal relationships for controls. *The first concept proposed was one utilizing master and slave “skeletons” which were virtually independent of each other.* That is to say, there were no attachments between master and slave other than the linkages producing error signals for position control.”

“Bilateral control with force feedback was to be used throughout the entire master from hand to foot.”

“Hardiman I Prototype Project”, General Electric, July 1, 1969, p 3-1.

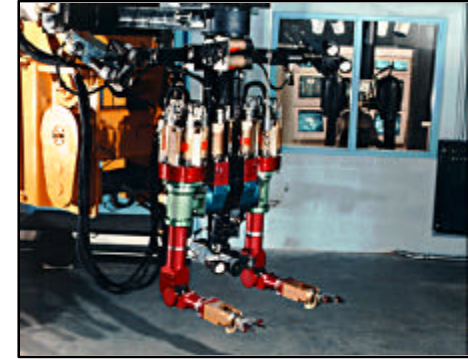
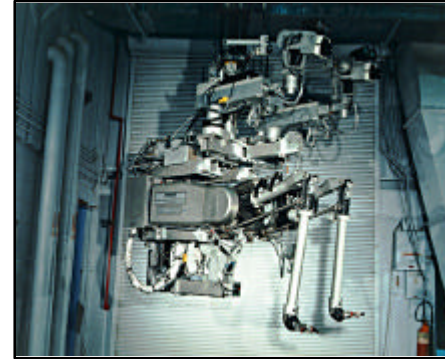
- Due to load forces transmitted through the mechanical arms to the leg structure and low feedback gains, the servos in the leg system were made non-force reflecting.



ORNL Has Long History in Teleoperations Controls

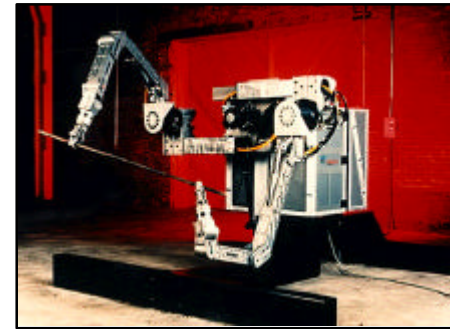
- **Position / Position Control**

- M2
- Advanced Servo Manipulator (ASM)



- **Position / Force Control**

- Dual-Arm Work Module



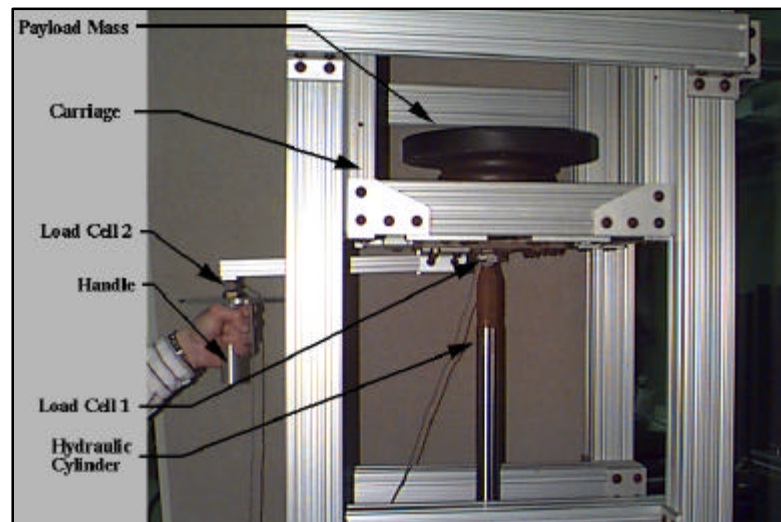
- **Force / Force Control**

- Next Generation Munitions Handler (NGMH)



• Key Advantages

- **One actuator per degree of freedom (dof)**
 - As opposed to two for conventional bilateral teleoperation
- **Operator “feels” :**
 - Part of static load
 - Dynamic load (i.e., contact forces, inertia load)
 - Virtual load (can add as appropriate)
- **Loads that the operator feels are scaleable in software**



Human Amplification Teststand

Additional Key Relevant Points about NGMH System

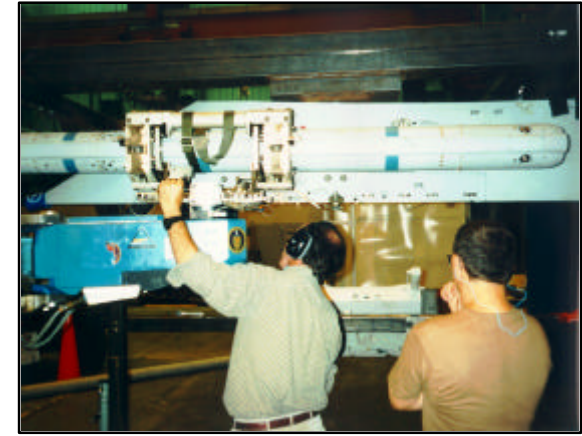
• Contact Stability / Impact Control

– Patent pending

- Jansen, J. F., "Apparatus and Methods for a Human Extender", Patent Pending U. S. Serial No. 09/253,436 for Lockheed Martin Energy Research.

– Impedance like control

- Achieved on large payload system (5,000 lb) scalable to lower capacities



NGMH Loading Missiles

• Safety / Fault Detection

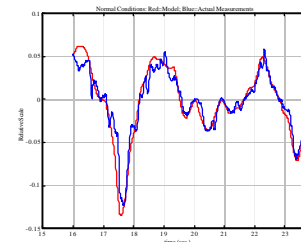
- Critical considering required operator/machine synergy

– Detecting failure of:

- Sensors
- Servo valves
- Drive electronics
- Actuators, etc

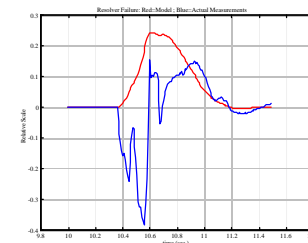
- Currently detecting within 200 mSecs

- Target: <100 mSecs



Normal Sensor Operation:
Red: Model
Blue: Measurement

Sensor Failure:
Detected < 200mSec
Red: Model
Blue: Measurement



- **Actuators & Control Elements Efficiencies**
 - **Electric Motors fundamental limitations:**
 - **Magnetic flux density in supporting structures**
 - **Heat Transfer out of actuators**
 - **ORNL currently working to improve power density (~3x)**
 - **Hydraulic Actuators 10x to 20x higher in power/weight ratios**
 - **Inefficiencies due to pressure drop across flow restriction control elements (i.e., orifices)**
 - **New approaches in precision hydraulic controls:**
 - **Digital valves**
 - **Hydrostatics**
- **Payload/Weight Ratios**
 - **IRAD study**

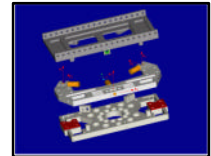


IRAD Research Arm

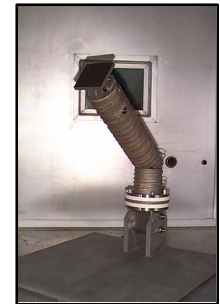
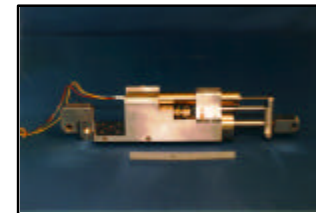
- **Working Many of Key Issues Pertaining to Soldier Enhancement for Decades**
 - Advanced controls, operator/machine synergy, human
- **Unique Hardware Experience**
 - Designing & building custom components when required (i.e., sensors, actuators, etc)
 - One of a kind systems using new technologies for unique challenges
- **Extensive Experience Integrating New Technologies into Prototypes & Working Systems**
 - Close coupling of controls modeling & simulation, mechanical design, systems integration -> *New, Novel Capabilities*
 - Unique multidisciplinary resources



**NGMH 6Axis Force
Torque Sensor**



**Custom Hydraulic
Actuator for High
Temperature
Manipulator Test Stand**



NGMH System Testing

